# Retrofitting of cottage basin ovens used in silk reeling industry

Project report

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# 1.0 Introduction

## 1.1 Preamble

In an earlier project, sponsored by SDC (Swiss Agency for Development and Co-operation), a detailed study of existing ovens used in silk reeling industry was carried out as a part of the main project on "Sector study in view of sector policy of SDC in the area of environment and energy in India". The objectives of the study were to review existing designs of ovens used, identify bottlenecks, if any, resulting in poor efficiency and suggest possible options of retrofitting or alternate designs which can improve the energy efficiency of the system.

After carrying out an extensive survey of 236 ovens in the field and conducting detailed energy and water balance experiments on a few selected units, two options emerged.

(i) retrofitting of the existing ovens
(ii) developing gasifier based silk reeling oven system

Details of the retrofitting of the cottage basin oven, its performance evaluation after retrofitting etc. are described in this project report. The second option of gasifier based design is now being executed by TERI as a separate project in itself, under the sponsorship of SDC.

## 1.2 Scope of the present study

An overview of the silk reeling industry, with special reference to energy use, is given in an earlier report[1]. Considering the fact that cottage basin ovens consume fuelwood unlike charkha ovens which use locally available biomass, they need immediate attention in order to address the problem of rapid deforestation in the area. Energy saving in cottage basin ovens can go a long way in alleviating the deforestation problem. Considering the low profit margins in reeling industry, any new alternate design requiring substantial capital investment may initially have problems of low acceptability. Also, there can be an inertia to change from traditional methods and go for new technologies. So, retrofitting of ovens has the potential to effect fuel savings with lower investments in the immediate future, provided it is accepted and practiced widely.

The scope of present study covers:

Retrofitting of a few cottage basin ovens.

Performance evaluation of retrofitted ovens through detailed energy and w[illegible] balance experiments.

Analysis of the results.

# 2.0 Analysis of the existing cottage basin ovens

## 2.1 Stove designs

In the cottage basin system the cooking operations and the reeling operations are carried out separately. The cocoons are first cooked in the cooking oven and then taken to the reeling basins for reeling.

The cooking oven consists of a masonry structure of a convenient height in which several — usually four to six, cooking pans are embedded in rows. The basins are normally made of copper or aluminum. They are 20 to 22 cm in diameter and about 20 cm in depth. The oven is provided with an ash pit, grate and chimney for the flue gases to exit. In the path of exhaust gases a large metallic water drum is provided to serve as a heat recovery system. The hot water is re-used in the process. There is a great variety, both in overall design and in dimensions in the traditional ovens. Some of the varieties are shown in Figures 2.1 to 2.4. The variations are as follows:

1. Some ovens have a horizontal grate (Figures 2.1 and 2.2) whereas others have an inclined step grate (Figure 2.3).
2. Many ovens have two chimneys, as shown in Figures 2.1 and 2.2 and some have only one (Figures 2.3 and 2.4).
3. The dimensions of the combustion space vary widely. For example, the height of the combustion space varies from 30 to 40 cm and width varies from 80 to 95 cm.
4. The hot water drum is only partially buried into the oven structure, implying low waste heat recovery. Metallic drum, made up of copper or steel is generally used (Figures 2.1 to 2.3) but sometimes it can be of different shape (Figure 2.4).
5. The arrangement of vessels in the oven structure varies a lot. Sometimes the vessels (up to 5) are in a single row (Figure 2.1), whereas in some ovens they are evenly spaced (Figures 2.2 to 2.4).

The improved oven designed by CSTRI for a 4-pan oven is shown schematically in Figure 2.5. It should be noted that the main differences between the CSTRI oven and an equivalent traditional oven are as follows.

1. A door is provided for feeding pieces of firewood. All the air required for combustion comes through the grate, hence there is a reasonable control on the excess air.

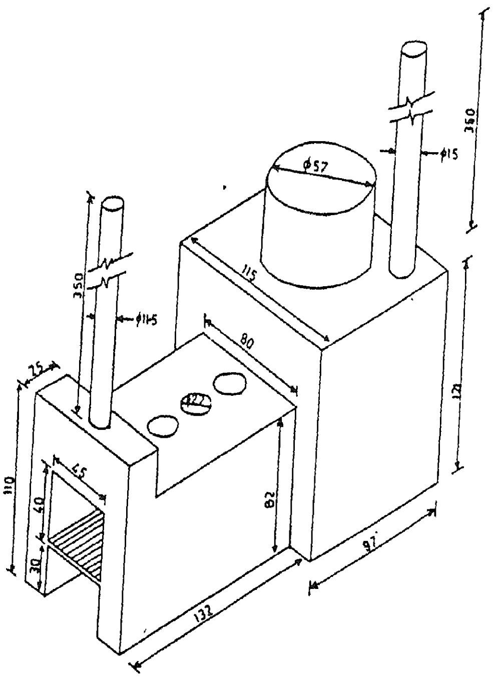

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**Figure 2.1.** Traditional cottage basin oven with 2 chimneys and single row of cooking basins

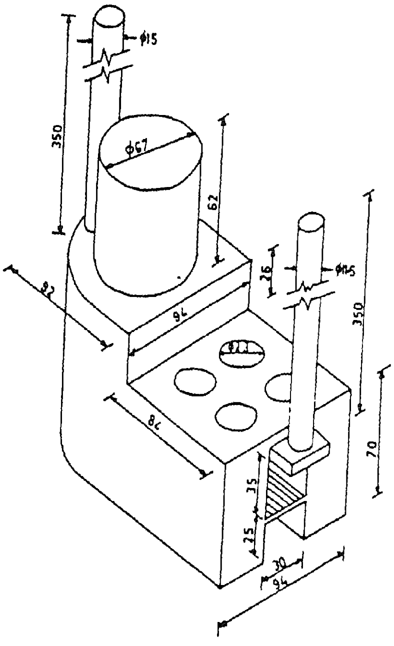

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**Figure 2.2.** Traditional cottage basin oven with 2 chimneys and two rows of cooking basins

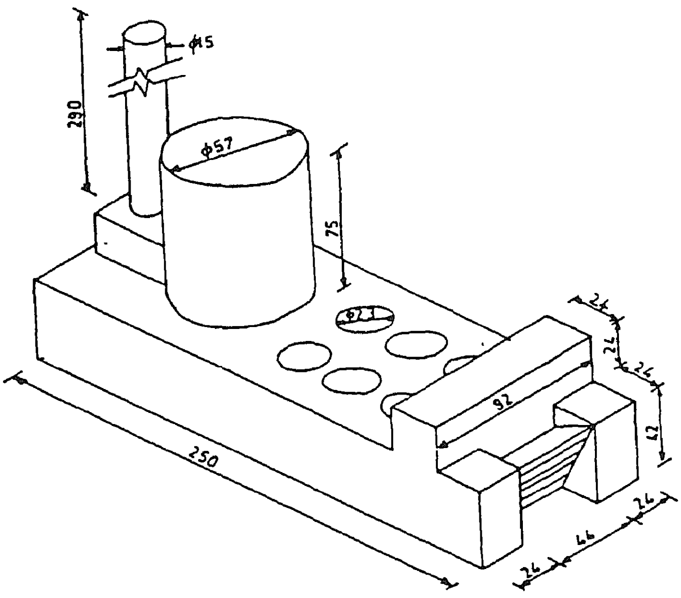

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Figure 2.3. Traditional cottage basin oven with stepped grate

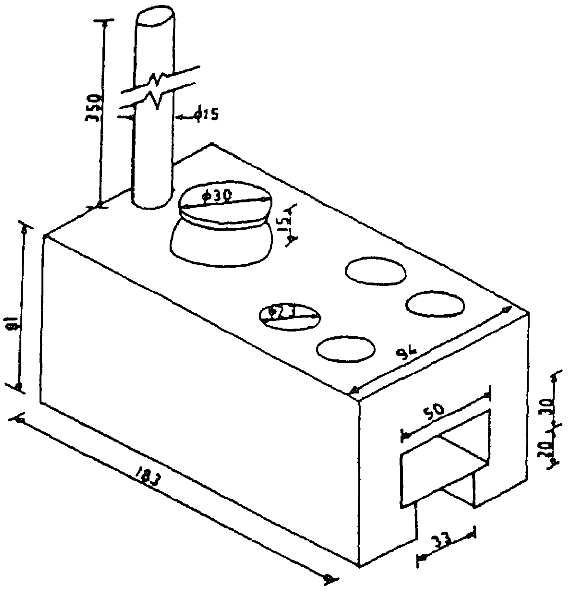

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Figure 2.4. Traditional cottage basin oven with different size/shape water preheater

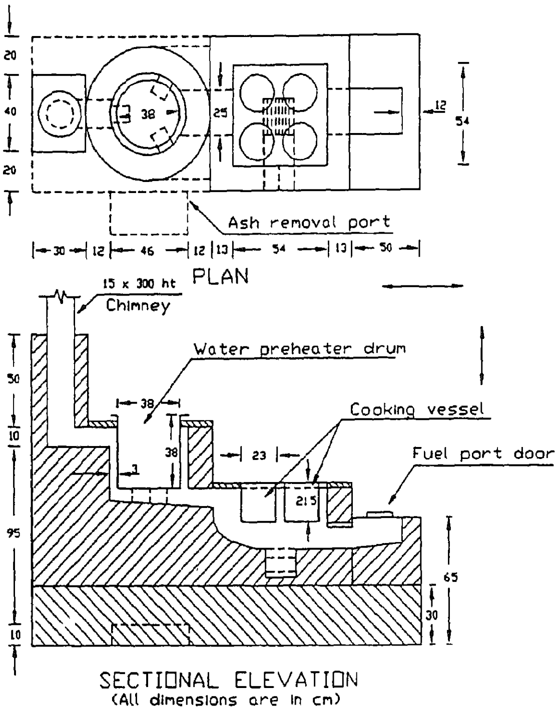

**Figure 2.5.** Schematic diagram of 4 pan CSTRI cottage basin oven

2. The volume of the combustion space is lower. This ensures lesser losses and a better efficiency of heat transfer to pots.
3. The hot water drum is completely surrounded by flue gases and hence the waste heat recovery is much better.

Because of these design changes, the improved oven should be consuming much less fuel than the traditional ovens. However, survey and measurements show that the fuel savings in the improved ovens are marginal, as detailed in the earlier report[1].

During the survey, it was observed that the improved ovens installed in the field are generally not as per the design. The main difference is that the fuel feeding door is removed and the front portion is broken open so that logs can be fed into the oven directly. This change is effected either after the oven is constructed or during the construction itself. The later versions of improved ovens probably do not have a fuel feeding door. Thus, there is essentially no control on excess air, resulting in heavy flue losses.

In order to get a clear understanding of how the various design changes and current practices affect the performance of the ovens, detailed studies were undertaken, as described in the following sections.

## 2.2 Performance analysis of existing cottage basin ovens

In an earlier study, detailed energy and water balance experiments were carried out in 4 (1 traditional and 3 CSTRI) cottage basin ovens[2]. The control volume considered for water and energy balance was the cooking basin.

In a cooking operation such as the one carried out in silk reeling, it is difficult to define thermal efficiency because many heat losses are inherent in the process itself. Such losses include evaporation from the cooking vessels, thermal energy in water exchanged from the cooking basins to reeling basins and the drainage loss at the end of each batch to replace dirty hot water with fresh clean water. For convenience, these were also included in the useful heat while calculating the thermal efficiency. The unutilized part of heat consists of various heat streams representing loss of heat by different routes. These energy streams include:

(i) flue gas loss (heat carried away through chimney in the form of hot flue gas).

(ii) heat loss through oven openings (heat transfer by radiation mode from fuel bed and flame to ambient through fuel port and other oven openings, if any.

(iii) surface heat loss (loss of heat by conduction, convection and radiation from hot oven surface to surrounding air).

(iv) heat loss due to oven thermal mass (heat accumulated by oven structure due to heat capacity of oven material, which is ultimately lost to ambient).

(v) unaccounted portion of heat loss including loss through hot ash and heat content of charcoal formed during operation which could not be monitored as it was used in operations like re-reeling.

There was no significant difference between the CSTRI ovens and traditional ovens as far as various energy streams are concerned.

The results of energy balance experiments are shown in Figure 2.6 in the form of a Sankey diagram.

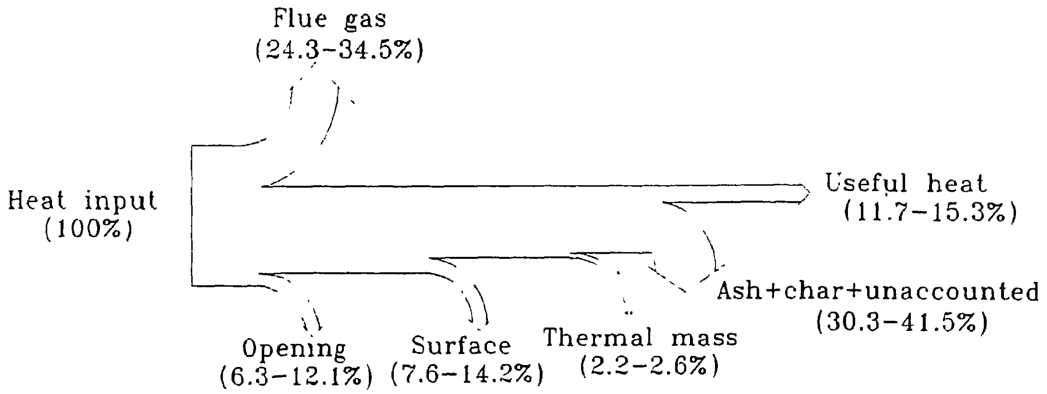

**Figure 2.6.** Sankey diagram showing various heat streams of traditional cottage basin oven

It can be observed from the Sankey diagram that the present ovens operate with a low thermal efficiency of the order of 10–15%. Flue gas carries away major share of heat loss to the tune of 24–35%, followed by surface heat loss (8–15%), heat loss through larger fuel port opening (6–12%) and heat loss due to thermal mass of heavy masonry structure (2–3%). Due to frequent removal of charcoal for re-reeling operation, there is a substantial (30–42%) portion of unaccounted heat loss. This also includes heat loss due to spillage of hot water by operator which was difficult to measure. The large variation in spillage heat loss is due to wide variation in operating practice followed by workers in different units.

This diagram can be taken as a reference to compare the performance of a retrofitted system.

# 3.0 Retrofitting of cottage basin ovens

## 3.1 Methodology of retrofitting

A team consisting of Prof. S S Lokras. ASTRA. IISc. Bangalore. scientists from TERI and scientists from CSTRI, was formed to explore the possibility of retrofitting a few ovens in the Kanakapura region. It was broadly decided that CSTRI will identify owners of traditional ovens who would agree to carry out retrofitting. After this, retrofitting would be done under the supervision of Prof. Lokras, and the entire cost of retrofitting was borne by the current project. After the retrofitting is completed, TERI team would conduct experiments to evaluate the thermal performance of the retrofitted ovens.

In all, three traditional 6 pan cottage basin ovens were selected by CSTRI for retrofitting. As the dimensions of the ovens are all different, the retrofitting was also slightly different for each case. However, the broad changes effected were as follows.

- A metal door was provided on the fuel port opening with a small (1" diameter) hole in it which provides a controlled quantity of air needed for complete combustion of fuelwood logs. The door should be closed always except at the time of charging fuelwood.
- The gap between grate and cooking vessels was reduced for the last two cooking vessels so as to enhance heat transfer rate in the later portion of cooking oven.
- The annular space around the water preheating drum, through which hot flue gases pass before entering the chimney, is gradually reduced from bottom (entry level) to top (exit level).

The retrofitting turned out to be a major operation. The old ovens had to be practically dismantled and then reconstructed. The old cooking oven was demolished and reconstructed using same metallic parts so as to incorporate new design modifications suggested above in the oven. The sketch of retrofitted oven at Mr Seshagiri's unit is shown in Figure 3.1. Photograph in Figure 3.2 shows the overall view of retrofitted cottage basin oven at Mr Sheshagiri unit and Figure 3.3 shows retrofitted oven at Mr G Girigowda's unit showing metallic door provided at fuel inlet port.

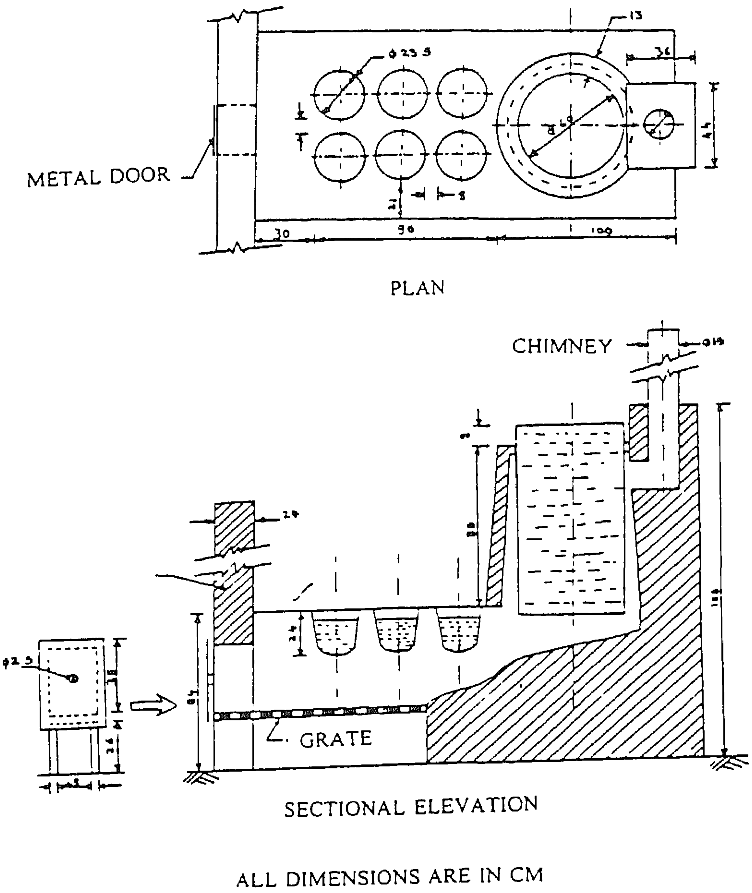

**Figure 3.1.** Sketch of retrofitted 6 pan cottage basin oven

**Figure 3.2.** Overall view of retrofitted cottage basin oven at Mr Sheshagiri's unit

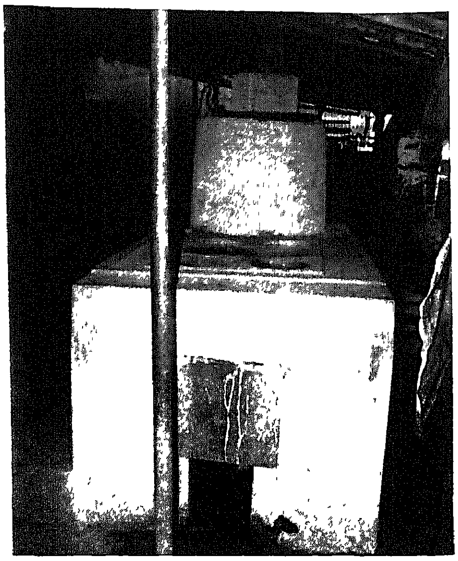

**Figure 3.3.** Overall view of retrofitted cottage basin oven at Mr Girigowda's unit showing metallic door at fuel port

## 3.2 Performance of retrofitted ovens

After the retrofitting was carried out, two of the three units closed operations and hence could not be monitored for performance evaluation. The third oven, belonging to Mr Seshagiri could, however, be monitored for performance immediately after retrofitting.

### 3.2.1 Experimental methods and measurements

Detailed energy and water balance experiments were carried out for one complete batch of a day. Various parameters were measured and monitored for this purpose.

**Water balance**

In order to carry out the water balance study the following parameters were monitored:

(a) Total water consumption for the batch (Figure 3.4)
(b) Water quantity in and out of the cooking basin (Figure 3.5)
(c) Water quantity drained after the batch for refill with fresh water
(d) Cocoon consumption for the batch (Figure 3.6)
(e) Quantity of pupae (secondary cocoons) recycled for the next batch (Figure 3.7)
(f) The temperature of the cooking basin and the feed water

Total water consumption for the batch was monitored by weighing a known quantity of water before the start of the batch. The weight of fresh cocoons was recorded every time the person cooking was about to put them into the basin. Along with this the recycled cocoons coming from the reeling basins were also weighed. This was done for the whole batch in order to know the ratio of fresh cocoons to recycled cocoons entering the cooking basin. Cooked cocoons were again weighed, immediately after taking out from cooking basin, before taking them to reeling basin. This gives the quantity of water carryover from cooking basin to reeling basin. The pupae from the cooking basin were collected separately in order to know the free water going out with them. At the end of the batch the drain off water was weighed as also the cocoons remaining for recycling in the next batch.

The main difficulty encountered during the experimental work was to monitor or measure the spillage losses and evaporation losses as there was no definite means to measure them, therefore evaporation loss was calculated by using formulas from the water temperature

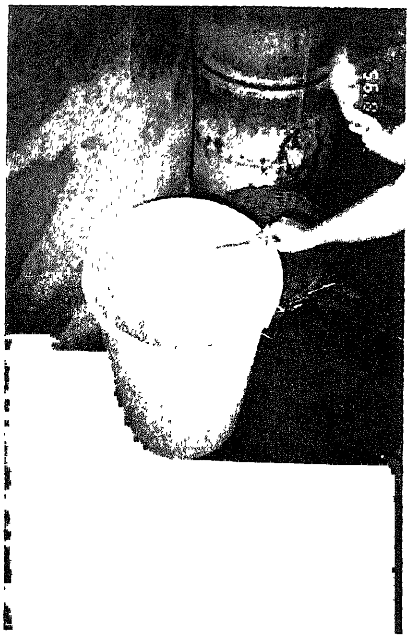

**Figure 3.4.** Measurement of water consumption during cocoon cooking process

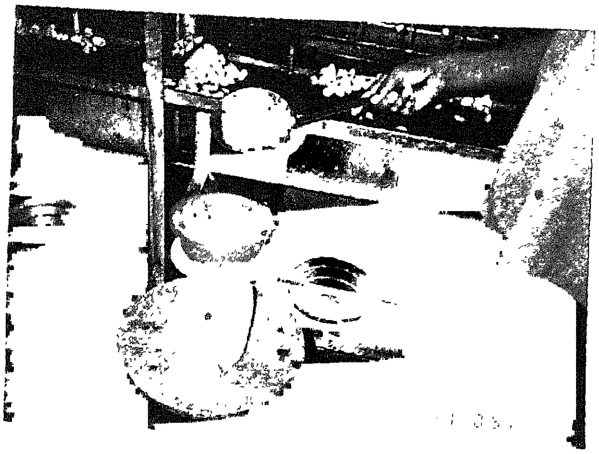

**Figure 3.5.** Weighing of cocoons before and after cooking to find out water carryover

**Figure 3.6.** Measurement of quantity of cocoons processed during batch

**Figure 3.7.** Weighing of pupae waste and cocoons recycled at the end of the batch

and ambient conditions (temperature and humidity) and spillage was calculated by difference. Summary of the water balance experiment is given in Table 3.1.

**Table 3.1.** Summary of water balance and useful heat data

| Retrofitted cottage basin oven | |
|---|---|
| No of pans | 6 |
| Cocoons processed (kg) | 16.8 |
| Fuel used | Tamarind wood |
| Fuel consumed (kg) | 20.7 |
| Duration (h) | 2 |
| Out/in water ratio for cooking basin | 2.49 |
| Water temperature (C) | 96 |
| **Water balance for the batch** | |
| Water, kg (%) | 124 (100) |
| Water carryover, kg (%) | 41.8 (33.7) |
| Water evaporated, kg (%) | 16.0 (12.9) |
| Water drained, kg (%) | 27.0 (21.8) |
| Pupae + water, kg (%) | 9.1 (7.3) |
| Possible spillage, kg (%) | 30.1 (24.30) |
| **Specific water consumption, (kg/kg cocoon)** | 7.4 |
| **Specific energy consumption, (kcal/kg cocoon)** | |
| Q-useful | 979 |
| Q-input | 5970 |
| **Specific fuel wood consumption (kg/kg cocoon)** | 1.23 |

It can be observed from the table that more than 7 litre water is consumed per kg of cocoon processed and water carry over contributes to about one-third of total water consumption followed by water spillage (24%), and water drainage (22%). It can also be seen that the useful heat required for cooking one kg of cocoons is about 979 kcal.

**Energy balance**

In order to arrive at the energy balance, the following parameters were monitored per batch of silk production.

(a) Fuel consumption (Figure 3.8)

(b) Oxygen, carbon dioxide (volume %) in the flue gases (Figure 3.9)

(c) Flue gas temperature

(d) Cooking basin temperatures (Figure 3.10)

(e) Drum water temperature (Figure 3.11)

(f) Reeling basin temperatures

(g) Dry bulb and wet bulb temperatures of surrounding area

(h) Temperatures of various oven surfaces

On the basis of various operating parameters recorded, heat balance calculations were carried out to estimate the heat losses in different heat streams. This also helps in assessing the magnitude of each type of loss and scope for its reduction. Sample energy balance calculations are given in Annexure A, B & C. The results of the energy balance are summarized in Figure 3.12, in the form of a Sankey diagram.

It can be seen from Figures 3.12 and 2.6 that there is a significant difference in the flue gas losses between the retrofitted oven and the conventional ovens. The flue gas losses account for about 12% for the retrofitted oven compared to a range of 25–35% for traditional and CSTRI ovens. The heat loss from fuel port is also less and heat recovered in the water drum is higher. As a result of reduced losses and improved waste heat recovery, the specific fuel consumption is at a low value of 1.23 kg/kg (cocoons), compared to a range of 1.5 to 2.5 kg/kg (cocoon) for traditional ovens.

It can thus be concluded that retrofitting resulted in a significant improvement in terms of overall thermal performance.

## 3.3 User's reaction

While conducting experiments on the retrofitted oven, the team did not get any negative feedback and hence it was assumed that the retrofitting was acceptable to the reelers.

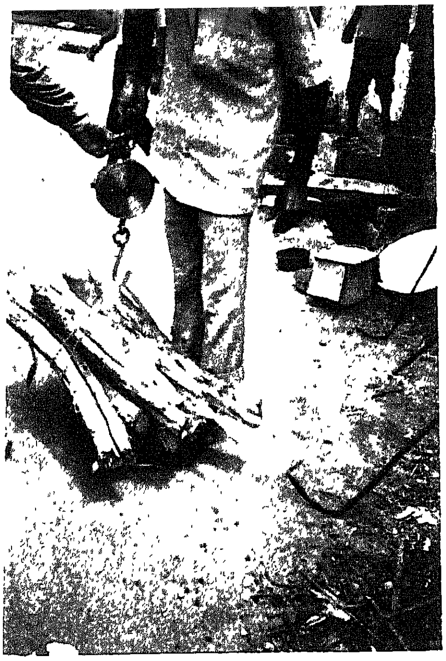

**Figure 3.8.** Measurement of fuelwood consumption during cocoon cooking process

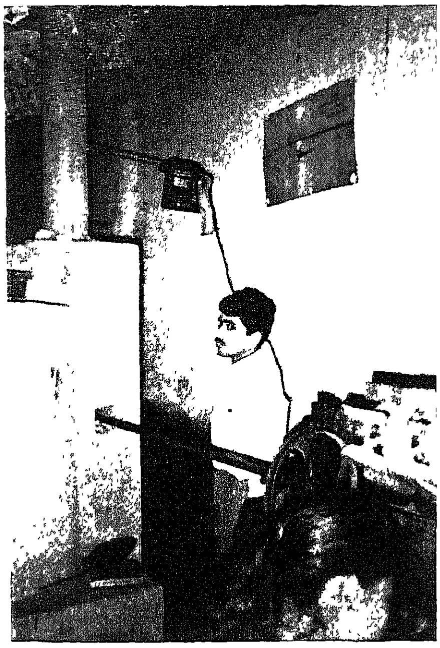

**Figure 3.9.** Measurement of $O_2\%$ in flue gas and its temperature using FEM-500

**Figure 3.10.** Measurement of cooking basin temperature variation with time

**Figure 3.11.** Measurement of water preheater drum temperature

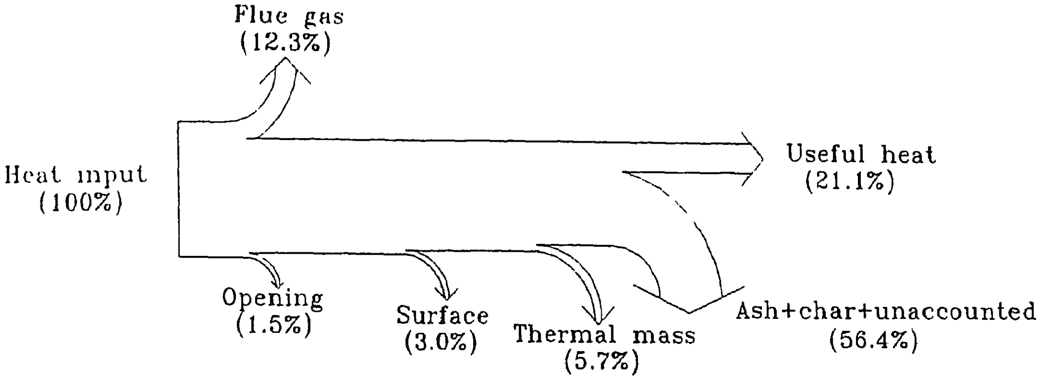

**Figure 3.12.** Sankey diagram showing various heat streams of retrofitted cottage basin oven

However, when the unit was revisited after a few months, it was found that the reeler made some changes both in the design and operation. An additional chimney was added in parallel to the one provided earlier as shown in Figure 3.13 and the fuel door was always kept open (Figure 3.14) in order to facilitate use of longer logs (as against smaller pieces recommended in the retrofit). While the opening of the fuel feeding door practically removed control on excess air, the additional chimney created a short circuit for flue gases, reducing the heat recovery drastically. Thus, the entire benefit of retrofitting was lost. The owner could not be contacted at that time to explain the reasons for making the above changes.

The most probable reason for the induction of a new chimney is a reduction in the natural draft caused by a gradual narrowing of the gap between the waste heat recovery drum and the flue gas passage, which could have been caused by deposition of particulate matter and tar. Without adequate draft, the burning would be slow, thus necessitating partial or full opening of the door. Another reason for keeping the fuel port open could be the reluctance of the labour to cut the logs into smaller pieces.

One more reason which prompted the reeler to make changes can be related to the thermal power of the oven. In the reeling operation, one cooking basin caters for two reeling

basins. i.e., the cocoons cooked in one basin are supplied to two workers doing the reeling operation on a continuous basis. As the reeling operation goes at certain speed (each reeling basin would have to process a certain amount of cocoons), the speed of cooking will have to match the requirement of reeling basins, which means the rate of rise of temperature for cooking basins (in other words, the power of the oven) should be at a certain minimum level. It is possible that the improvements made in the retrofitted oven from the angle of improved thermal efficiency might have reduced the power of the oven (for example, by reducing the overall draft), prompting the owner to alter the retrofit.

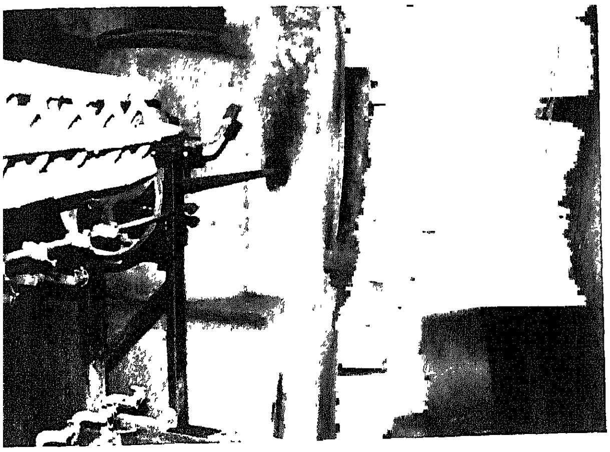

**Figure 3.13.** Photograph showing additional chimney installed by reeler

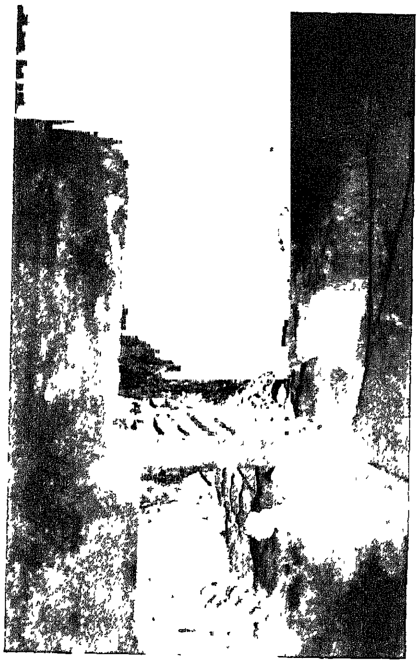

**Figure 3.14.** Open metallic door position to facilitate feeding of longer wood logs

The effect of changes made was so obvious that no efforts were made to conduct experiments again to determine the energy consumption of the oven. However, an attempt has been made recently to get the feedback of the owner in the form of a questionnaire. The response is shown in Annexure D.

## 4.0 Conclusions

It would not be proper to draw definite conclusions based on limited experience of monitoring only one retrofitted oven, but some broad inferences can be drawn, as listed below.

1. The dimensional and design variations of the oven from cluster to cluster and even within a cluster are far too wide to arrive at a unique design of retrofitting. The retrofit will have to be different for different ovens.
2. Retrofitting for efficiency improvements involves (a) control of combustion air by providing a closable fuel port, (b) reduction in the combustion space, and (c) increase in the waste heat recovery.
3. To effect the above changes, the existing oven will have to be practically demolished and rebuilt, and hence the cost of retrofitting is nearly equal to the cost of a new oven. The metal parts, i.e., the grate, cooking vessels and waste heat recovery drum, can of course be reused if they are in good condition.
4. Significant improvements in thermal efficiency and fuel savings can be achieved through retrofitting. Especially the flue gas losses can be reduced by about 50%. However, it is not clear if the retrofitting adversely affects the thermal power of the oven.
5. There is a need to educate and train the user to make him understand the cost implications of (a) using smaller wood logs and (b) keeping the fuel port closed.
6. If the retrofitting reduces the power of the stove, the production rate of silk yarn is affected and then the fuel savings will have no bearing on the operation of the oven.
7. Future work should concentrate on (a) studying the effects of retrofitting on the useful power obtained, (b) maintenance requirements of the retrofitted oven, and (c) quantifying the cost benefits and demonstrating the same to the user.

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2. Mande S, Pai B R and Kishore V V N, 1995. **Study of Stoves used in Silk Reeling Industry**. Paper presented at Workshop on Biomass Stoves for Institutional and Small Scale Industry Application, Yogyakarta, Indonesia.

# Annexure - A
## Calculation of flue gas flow rate through chimney

In the thermal analysis of any stove, the loss through chimney in the form of hot flue gases is the major fraction. During the operation of chulha/oven, much more excess air is supplied to the fuel than the stoichiometric air requirement for complete combustion of the fuel, due to draft created by the chimney. The quantity of air flow is quite low and therefore, difficult to measure with conventional techniques of flow measurement, like pitot tube or anemometer. The best and simplest way of estimating the flue gas flow rate in the field is to measure the composition of flue gas along with flue gas temperature and then estimate the excess air and flue gas flow rate. During the course of study a simple software was developed using lotus 1-2-3 spreadsheet to estimate the flue gas quantity for the burning of fuel from its composition, and by knowing the flue gas temperature and volume fraction of either $CO_2$ or $O_2$. The basic calculation procedure used is described below through a sample calculation for tamarind wood fuel by measuring $O_2$ fraction in the flue gas using Fyrite kit.

### *Fuel composition*

Composition of the fuel (tamarind wood) used, on weight basis is as follows:

Moisture = 7.23%, Ash = 8.43%, rest C, H, and O

The majority of biomass fuels have a more or less same composition (C = 50%, H = 12% and O = 38%) on a moisture and ash free basis. Therefore the actual weight of constituents (C, H, O) in the fuel works out to be

C = 0.422 kg = 0.035 kmol
H = 0.101 kg = 0.051 kmol
O = 0.321 kg = 0.010 kmol

### *Theoretical oxygen requirement*

For complete combustion of 1 kg of fuel, the theoretical oxygen required will be

$O_2 = (C \times 1) + (H \times 0.5) - (O) = 0.050$ kmol

Knowing the fact that air consists of 21% $O_2$ (oxygen) and 79% $N_2$ (nitrogen) by volume, the theoretical air required for complete combustion of 1 kg of fuel works out to 0.24 kmol.

### *Actual combustion reaction*

In actual practice, the amount of air supplied during the combustion of fuel is far more than theoretical air. This excess air is responsible for high flue gas losses through chimney. If 'X' is the excess air factor, the combustion reaction can be written as follows.

Reactants = Products

Reactants = $0.035\ C + 0.051\ H_2 + 0.010\ O_2 + (1 + X)\ 0.050\ (O_2 + 3.76\ N_2) + (0.072/18)\ H_2O$ ..... (1)

Product = $0.035\ CO_2 + 0.055\ H_2O + 0.19\ (1 + X)\ N_2 + 0.05\ X\ O_2$ ..... (2)

Balancing the various constituents C, H, O, N on both the sides, one gets a set of equations with X as a variable. Thus the value of X can be calculated if one knows any one fraction of gas in the products of combustion. As $CO_2$ and $O_2$ can be absorbed quickly, their volume fraction in the flue gas can be measured easily. In the present case, the $O_2$% was measured using a Fyrite kit (J N Marshal make), on a moisture free basis. The measured value for the present experiment was 10%. The mole fraction (or volume fraction) of $O_2$ in the flue gases, on a moisture free basis, can be obtained from equation 2 and can be equated to the measured value.

$$\frac{0.05\ X}{0.035 + 0.19\ (1 + X) + 0.05\ X} = 0.10$$

Solving for X, we get

X = 0.867 = 86.7%

The quantity of flue gas under the given operating conditions can be determined by substituting the value of X in the products.

Flue gas = 0.433 kmol on moisture free basis

= 0.488 kmol including moisture

From the molecular weight of different flue gas components ($CO_2$ = 44, $O_2$ = 32, $H_2O$ = 18, $N_2$ = 28), the quantity of flue gas can be calculated as

Flue gas = 13.8 kg per kg of fuel

For a burning rate of 10.35 kg/h, the flue gas flow rate works out to be

= 132.7 kg/h

(Note: In the above calculation, the moisture content of ambient air is ignored)

# Annexure - B
# Sample calculation for energy balance of cooking oven

In this annexure, the procedure for carrying out energy balance of silk reeling ovens, is described in detail. The cooking oven performance was monitored for operation of one batch.

*Unit details*

| | |
|---|---|
| Type of oven | : Retrofitted cottage basin |
| No. of cooking basin | : 6 |

*Fuel details*

| | |
|---|---|
| Type | : Tamarind wood |
| Calorific value | : 4845 kcal/kg |
| Ash content | : 8.43% |
| Moisture content | : 7.23% |

*Parameters observed*

| | |
|---|---|
| Duration of batch | : 2 h (9.30 to 11.30) |
| Oxygen ($O_2$%) in flue gas | : 9.03% |
| Flue gas temperature | : 210 °C |
| Total fuel consumed | : 20.7 kg |
| Total cocoons processed | : 16.8 kg |
| Ambient conditions: DBT | : 31 °C |
| RH | : 74.8% |
| Feed water temperature | : 27 °C |
| Cooking basin temperature | : 96 °C |
| Metallic door temperature | : 230 °C |

*Oven measurements*

Complete oven details (geometric dimensions, construction material, etc.) required for the calculation of areas, weight of oven, heat transfer coefficient were measured and noted down. The dimensions are

| | |
|---|---|
| Width of metallic fuel port opening | : 0.235 m |
| Diameter of hole in metallic fuel port door | : 0.025 m |
| Height of metallic fuel port opening | : 0.360 m |
| Length/depth of fuel bed | : 1.600 m |

Based on the above parameters, calculation of various heat streams is described below.

*Heat input ($Q_{in}$)*

The total heat input through combustion of fuel in the oven can be calculated from the fuel consumption and its calorific value.

$Q_{in} = 20.7 \text{ (kg/batch)} \times 4845 \text{ (kcal/kg)} = 100291.5 \text{ kcal/batch}$

Theoretically, the net heat input will be less, as the heat content of the balance char should be deducted. But since the char obtained is utilized from time to time for re-reeling operation as well as for igniting fuel in the stifling oven, it was difficult to quantify the exact amount of char obtained in a batch. Therefore this was kept in the unaccounted heat loss.

### *Heat loss through flue gas ($Q_f$)*

From the calculation given in Annexure A, the flue gas flow rate ($M_g$) is 132.70 kg/h

Hence, $Q_f$

$$\begin{aligned} Q_f &= M_g C_{pg} (T_g - T_{amb}) \\ &= 132.70 \times 0.26 \times (210 - 31) \\ &= 6175.9 \text{ kcal/h} \\ &= 12351.7 \text{ kcal/batch} \end{aligned}$$

where,

$M_g$ = flue gas flow rate = 132.7 kg/h
$C_{pg}$ = sp. heat of gas = 0.26 kcal/kg °C
$T_g$ = flue gas temperature = 210 °C
$T_{amb}$ = ambient dry bulb temperature = 31 °C

### *Surface heat loss ($Q_s$)*

The heat loss from the oven surface takes place through two modes of heat transfer.

a) convection (natural)
b) radiation

Here the sample calculation of surface heat loss is given for one surface (right hand vertical side). Similarly the heat loss from other oven surfaces can be calculated to arrive at the total surface heat loss.

a) Convection heat loss ($Q_{s,c}$)

Wall surface temperature ($T_s$) = 44.3 °C
Surface area ($A_s$) = 1.840 m$^2$
Wall height ($H_w$) = 0.84 m = 2.76 ft
Temperature gradient ($\Delta T$) = $T_s - T_{amb}$ = 13.3 °C = 23.9 °F

For air as fluid, the natural convection heat transfer coefficient ($H_c$) can be obtained using the following equation.

$$h_c = C \left( \frac{\Delta T}{D} \right)^m$$

where,

$h_c$ = convective heat transfer coefficient = Btu/hft$^2$ °F
C & m = constants
D = geometric dimension (ft)

The values of C, m and D for various oven surfaces are as follows (Ref: Process Heat Transfer by D Q Kern):

| Surface | C | M | Dimension |
|---|---|---|---|
| Vertical | 0.28 | 0.25 | height |
| Top horizontal | 0.38 | 0.25 | 1.00 |
| Drum | 0.28 | 0.25 | height |
| Chimney | 0.40 | 0.25 | diameter |

Thus for right vertical side surface the heat transfer coefficient can be calculated as,

$$h_c = 0.28 \times \left(\frac{23.9}{2.76}\right)^{0.25}$$

$h_c$ = 0.48 Btu/h ft$^2$ °F = 2.34 kcal/h m$^2$ °C

Therefore,

$Q_{s,c}$ = $h_c$ A $\Delta T$
= 57.37 kcal/h = 114.7 kcal/batch

b) Surface radiation loss ($Q_{s,r}$)

Heat loss from the surface through radiation mode ($Q_{s,r}$), by virtue of temperature difference between wall surface ($T_s$) and surrounding ($T_{amb}$), can be calculated as

$$Q_{s,r} = \sigma \; \epsilon \; A_s(T_s^4 - T_{amb}^4)$$

where,
$\sigma$ = Stefan Boltzman constant = 4.88 × $10^{-8}$ kcal/h m$^2$ K$^4$
$\varepsilon$ = Emissivity of wall surface
$T_s$, $T_{amb}$ = Surface and ambient temperature in °K

Therefore,

$Q_{s,r}$ = 93.1 kcal/h = 186.3 kcal/batch

Therefore, the total loss from the right hand side vertical surface becomes,

$Q_s$ $= Q_{s,c} + Q_{s,r} = 114.7 + 186.3 = 301.00$ kcal/batch

In a similar manner the surface heat loss from other oven surfaces can be calculated. Thus total surface heat loss becomes

$Q_s$ = 1502 kcal/h
= 3004 kcal/batch

***Heat loss from oven opening ($Q_o$)***

One of the main modifications made during retrofitting is providing metallic door with very small (1" diameter) hole so as to allow sufficient air needed for combustion of wood. Thus door acts like radiation shield reducing the radiative heat loss from red hot fuel bed to ambient through fuel port opening. The more number of radiation shields the less is radiative heat loss as:

$$Q_{r,\text{with shield}} = \frac{Q_{r,without\ shield}}{n+1}$$

Where 'n' the is number of radiation shield. Thus, metallic fuel port door (n=1) reduces the radiative heat transfer by half of that without shield.

$$Q_{o\,r} = 1/2\ Q_{r,wd}$$

In order to estimate the amount of heat loss from the fuel bed through the fuel port opening without door ($Q_{r\,wd}$), it is necessary to calculate the view factor (also called as radiation shape factor) between the fuel bed (grate) area and fuel port opening of the oven. This can be determined using the following two ratios.

Ratio 1 = depth/width = 1.6/0.235 = 6.8
Ratio 2 = height/width = 0.36/0.235 = 1.53

Then, referring to the graph given in Figure 4.9 of 'Process Heat Transfer' by Kern and Krause, for the above two ratios, the view factor (VF) works out to be 0.05. With fuel bed temperature ($T_b$) of 1300 °C (1573 °K), the radiation heat loss through oven opening becomes

$$Q_{r,wd} = \sigma \times A \times VF \times (T_b^4 - T_{amb}^4)$$

$$Q_{r\,wd} = 4.88 \times 10^{-8} \times 0.0846 \times 0.05 \times (1573^4 - 304^4)$$

$$= 1262 \text{ kcal/h}$$

Thus, radiative heat loss from fuel port opening with door in retrofitted oven is:

$$Q_{o,r} = 1/2\ Q_{r,wd}$$
$$= 631\ \text{kcal/h}$$

In addition to this, the hot fuel port door also transfers heat by natural convection ($Q_{o,c}$). The convective heat transfer coefficient ($h_{c,d}$) for vertical hot metallic door can be calculated similar to the procedure explained earlier while calculating surface heat loss from oven walls.

$$h_{c,d} = 0.28 \left(\frac{358.2}{1.18}\right)^{0.25}$$

$$= 117\ \text{Btu/h ft}^2\ {}^\circ\text{F}$$
$$= 5.7\ \text{kcal/h m}^2\ {}^\circ\text{C}$$

Thus convective heat transfer from metallic door surface to ambient ($Q_{o,s}$) can be calculated as:

$$Q_{o,s} = h_{c,d} \times A_d \times (T_d' - T_{amb})$$
$$= 5.7 \times 0.0846 \times (230 - 31)$$
$$= 95.96\ \text{kcal/h}$$

Therefore, total heat loss through fuel port opening becomes

$$Q_o = Q_{o,r} + Q_{o,s}$$
$$= 631 + 95.9$$
$$= 726.9\ \text{kcal/h}$$
$$= 1453.9\ \text{kcal/batch}$$

***Heat loss due to thermal mass of oven ($Q_m$)***

During the operation of oven throughout the day, the oven gets heated up by absorbing the heat due to the thermal mass of the various structural components. This accumulated heat is liberated back to the surrounding atmosphere when the oven is not operational. Hence it is assumed, that the oven returns to its original temperature in a daily cycle. Here, a calculation is made for the right side vertical wall of the oven.

Mass of the wall = volume × bulk density
= (Area × thickness) × bulk density
= (1.84 × 0.25) × 2000 = 920 kg

$$Q_{m,rhs} = M_{wall} \times C_{p,wall} \times \Delta T$$
$$= 920 \times 0.596 \times (44.3 - 31.0)$$
$$= 7128.2\ \text{kcal}$$

This heat is lost throughout the day. Since the oven under consideration operates for 10 h/day, and the batch under study is of 5 h duration, the contribution of heat loss due to thermal mass for the batch under study can be calculated as,

$$Q_{m,rhs} = 1425.6\ \text{kcal/batch}$$

The heat loss due to thermal mass of other oven component can be calculated in a similar way. The total heat loss due to thermal mass of the oven under consideration amounts to

$Q_m$ = 5670 kcal/batch

*Useful heat ($Q_u$)*

The useful heat required for cooking the cocoons is calculated by a detailed water (and heat) balance exercise, as described in Annexure C. The useful heat for the cooking process works out to be

$Q_u$ = 979.1 kcal/kg cocoon = 16450 kcal/batch

***Heat recovered in water preheater drum ($Q_{dr}$)***

The amount of heat recovered from the gases for heating the water in drum is calculated separately as follows.

Temperature rise during batch = 70.3 - 49.7 = 20.6 °C

Average water temperature in drum = 60 °C

Sensible heat of water ($Q_{sensible}$) = Quantity of water used/batch × $C_p$ × $\Delta T$
= 140 × 1 × (70.3 - 49.7) = 2884 kcal/batch

Rate of evaporation of water from drum surface (g/h $m^2$) can be calculated as

$m_{ev}$ = constant × 45.8 × ($p_w$ - $p_a$)

where

$p_w$ = vapour pressure of water
$p_a$ = partial pressure of water vapour in ambient air

constant = 0.81 for faster relative movement of water
= 0.55 for still water

Vapour pressure at 60 °C = 196.6 millibar

Vapour pressure at 31 °C (DBT) = 44.6 millibar

Partial pressure of water vapour in air = Relative humidity × $P_{sat}$
= 0.75 × 44.6 = 33.5 mbar

Top surface area = $(\pi/4)\ D^2 = (3.14/4) \times (0.585^2) = 0.268\ m^2$

Rate of evaporation = 0.81 × 45.8 × (196.55 - 33.45) = 6050.7 g/h $m^2$
= 6.05 kg/h $m^2$ = 1.62 kg/h

$Q_{evap}$ = evaporation rate×(latent heat + $\Delta T$)
= 1.62×[540 + (60 - 31)]
= 921.8 kcal/h = 1843.6 kcal/batch

$Q_{drum}$ = $Q_{sensible}$ + $Q_{evap}$
= 4727.6 kcal/batch

Various heat streams calculated are summarized in table B-1.

**Table B-1: Summary of energy balance calculation**

| **Heat stream** | **Quantity (kcal/batch)** | **Percentage** |
|---|---|---|
| Heat input ($Q_i$) | 100291 | 100.0 |
| Flue gas loss ($Q_f$) | 12352 | 12.3 |
| Surface loss ($Q_s$) | 3004 | 3.0 |
| Fuel port opening loss ($Q_o$) | 1454 | 1.5 |
| Thermal mass loss ($Q_m$) | 5670 | 5.7 |
| Useful heat ($Q_u$) | 16450 | 16.4 |
| Drum heating ($Q_{dr}$) | 4727 | 4.7 |
| Total heat accounted for ($Q_{tot}$) | 43657 | 43.6 |
| Unaccounted ($Q_{ua}$) (including ash + char) | 56634 | 56.4 |

# Annexure - C
# Sample calculation for water balance of cooking basin

For estimation of useful heat of a silk reeling oven, it is essential to estimate the various water flows. This is not an easy task, as water carryover takes place from cooking to reeling basins and vice versa. In order to arrive at the net quantity of water going out from cooking basin to reeling basin, the weights of cocoons both before putting into the cooking basin and after cooking (before taking it to reeling basin) were monitored continuously for one batch. For the traditional cottage basin under consideration, the ratio of water taken out from cooking basin to that going into it worked out to 2.5.

In order to monitor water flow, the main water supply was stopped and the workers were asked to take water from a tank with graduations. The workers were also asked to give the cocoons for weighing before and after cooking. Also, the pupae waste, water drained, jute waste produced, pupae recycled, etc. were measured during the batch. The summary of data collected during monitoring is given below for one batch.

| | |
|---|---|
| Cocoons processed | = 16.8 kg |
| Water consumption | = 124 kg |
| Water out/in ratio for basins | = 2.487 kg/kg cocoon |
| Duration of batch | = 2 h |
| Cooking basin water temperature | = 96 °C |
| Feed water temperature | = 29 °C |
| DBT | = 31 °C |
| RH | = 74.8% |
| Pupae waste | = 9 kg |
| Water drained | = 27 kg |
| Water spillage (by difference) | = 30.2 kg |
| Jute waste produced | = 3.8 kg |

Water evaporated from the open surface of the cooking basins is calculated as follows:

Rate of evaporation = $c \times 45.8 \times \Delta P$ g/h m$^2$

where

c = 0.81 for faster relative movement
= 0.55 for still water
$\Delta P$ = vapour pressure difference

| | |
|---|---|
| Saturated vapour pressure of water at 96° C | = 869.1 millibar |
| Saturated vapour pressure at DBT | = 44.60 millibar |
| Partial pressure of water in air at the given RH | = $0.75 \times 44.6$<br>= 33.5 millibar |
| Rate of evaporation | = $0.81 \times 45.8 \times (869.1 - 33.5)$<br>= 31001.6 g/h m$^2$ = 31.0 kg/h m$^2$ |

The total area of all the six cooking basins is 0.38 $m^2$.

Total evaporation = 31.0 × 0.38
= 7.99 kg/h or 16 kg/batch

The various water streams flowing into and out of the control volume are shown in Figure C-1.

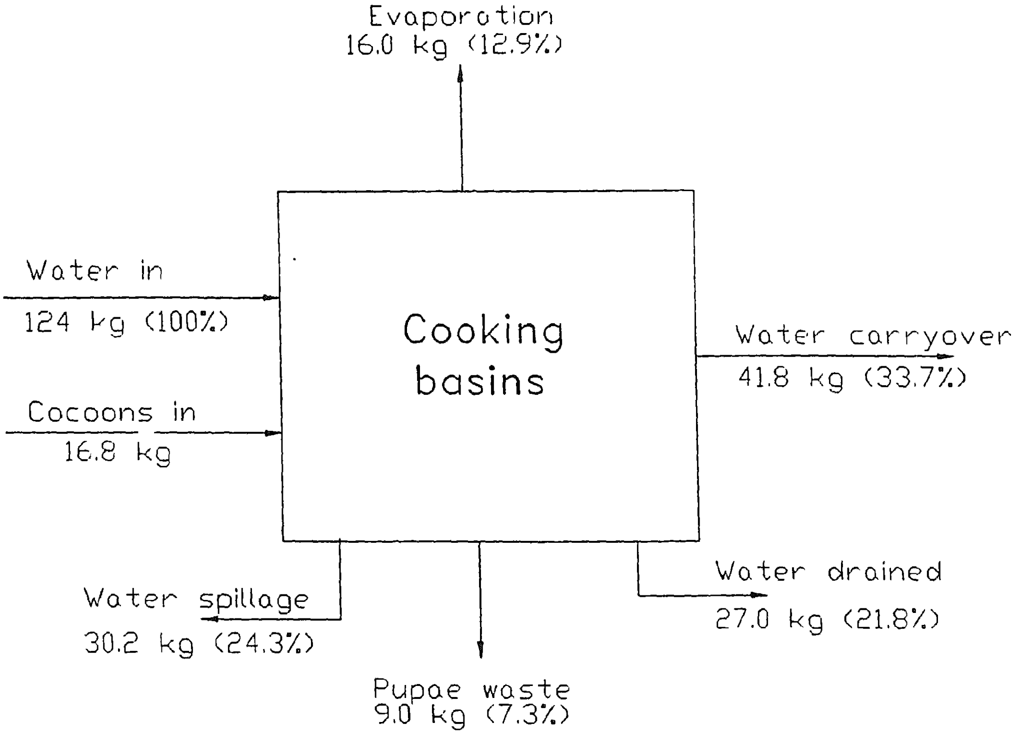

**Figure C-1.** Water balance of cooking basins

Assuming that the fresh cocoons are at 29 °C (feed water temperature) and that the specific heat of pupae waste and cocoons is qual to that of water, the heat balance for the control volume can be carried out as follows to obtain the useful heat.

$Q_{in} = Q_{cocoon} + Q_{water\ in}$
$= (16.8 + 124) \times 29 = 4083.2$ kcal/batch

$Q_{out} = Q_{carryover} + Q_{drain} + Q_{pupae} + Q_{spillage} + Q_{evap}$
$= (41.8 + 27 + 9 + 30.2) \times 96 + (16.0) \times (540 + 96)$
$= 10369.9 + 10163.3 = 20533.2$ kcal/batch

$Q_{use} = Q_{out} - Q_{in}$
$= 16450$ kcal/batch
$= 979.1$ kcal/kg cocoon

# Annexure - D
# Summary of discussions of Mr S N Srinivas with Mr Seshagiri Rao, Kanakapura and earlier response to questionnaire

Date of visit of Mr Ninga Setty to get questionnaire response : 15 January 1997

Date of meeting between Mr Srinivas and Mr Seshagiri : 8 March 1997

## I. General information

Name : Mr Seshagiri Rao
Address : Seshagiri Silk Reeling Unit
Kotte
Kanakapura - 562 117

## II. Specific information about the unit

| Parameter | Old oven | Retrofitted oven | Modified retrofitted oven |
|---|---|---|---|
| Operation | 1985 to September 1995 | September 1995 to February 1996 | Since February 1996 |
| Quantity of cocoon processed | 100 kg per day | | |
| Amount of silk yarn produced | 10 kg per day | | |
| Type of fuel wood used | Tamarind, Kaggali, Dindiga | Chujjali, Tamarind, beru (50% hard wood + other waste wood) | |
| No. of cooking basin | 6 | | |
| Capacity of water preheater drum | 220 litre copper drum | | |
| Chimney size | 6" dia (1 no) | 6" dia (1 no) | 6" dia (2 nos) |
| Wood consumption | 150–200 kg/day | 100-120 kg/day | |

## III. Retrofitting details

- When was retrofitting done?
  - In September 1995

- What changes were made in the original oven in the course of retrofitting:
  - Metallic door with small hole at fuel port opening.
  - Reduced thickness of slab.
  - Less distance between oven grate and vessels.
  - Complete covering of preheater drum with gas flowing around in annulus with reduced gap from bottom to top.
- How was the performance of retrofitted oven compared to old oven?
  - Better
- Which were positive points in retrofitted oven?
  - Fuel wood savings of abut 20 kg per day.
  - Quick rise of water temperature in preheater drum.

## IV. Post retrofitting details

- Whether modifications were made in retrofitted oven? If yes, when?
  - Yes, in February 1996
- What made (prompted) him to do changes?
  - For convenience of operation to allow use of large wood logs.
  - For faster cocoon processing.
- What are the specific changes made in retrofitted oven.
  - Additional chimney on back side
  - Keeping door always open.
- How was performance improved after changes?
  - Better power
  - Better smoke removal.

Notes: There was no significant difference in silk yarn yield or quality. The unit was not running for past 3–4 months because of higher cocoon price and its shortage.